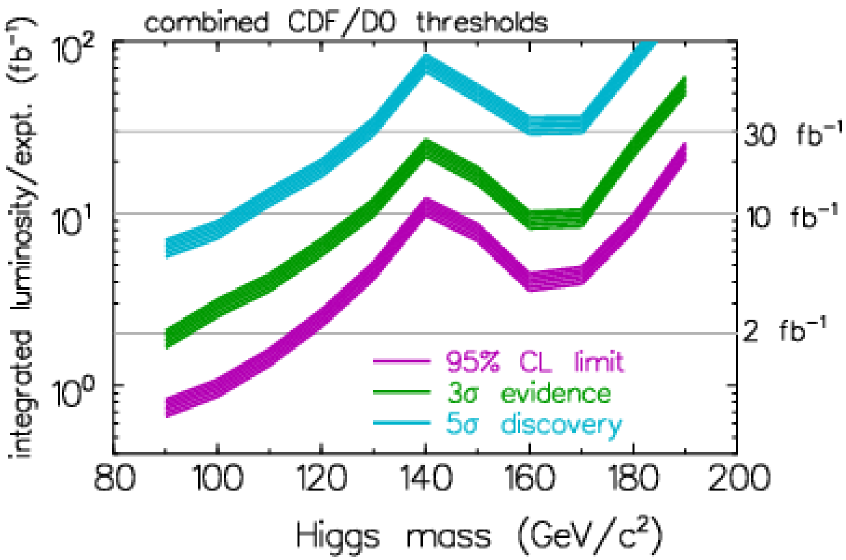
DO Run 2b Project

- Run 2b Project overview
  - Motivation
  - Design guidelines
  - Overall approach
  - Sub-project overviews
  - Organization
- Silicon replacement
- Trigger upgrades
- Project status: responsibilities, cost, schedule
- Conclusions

Jon Kotcher
FNAL Department of Energy Review
March 19-21, 2002

Run 2b Motivation

- Direct probe of Higgs sector unique to Fermilab program until turn-on of LHC
- Laboratory: determine experiment's needs in order to optimize Higgs reach, exploit luminosity during next 5+ years
- 15 fb^{-1} per experiment probes M_H ~ 185 GeV/c^2 (3σ)
  - LEP limit (F. Cerutti, LaThuille '02)
    - $M_H > 114.1\ GeV/c^2$ (95% CL)
  - Latest global fit to electroweak data (A. Tonazzo, LaThuille '02)
    - $M_H = (85^{+54/-34})\ GeV/c^2$
    - $M_H < 196\ GeV/c^2$ (95% CL)
- Prospects for Higgs search at Fermilab continue to be very positive
  - Opportunity unique, time scales finite
  - Requires fast, efficient definition and ramp-up of projects, application of resources – accelerated approach
  - Experiment, laboratory collaborating very closely together to realize this



Run 2b Design Guidelines

- Run 2b: increase in instantaneous, integrated luminosity relative to guidelines that drove Run 2a detector design

	Integrated Luminosity (fb^{-1})	Instantaneous Luminosity ($X10^{32}cm^{-2}sec^{-1}$)
Run 2a	2	2
Run 2b	15	4-5
Requirements for Run 2b	Silicon replacement, more rad-hard version	Trigger upgrades (dominated by Level 1)

- Silicon:
  - Current detector designed for ~ 2 fb^{-1}, evidence that it will survive to 4-5 fb^{-1}
    - The most appropriate rad-hard technology used at that time
  - After study of various options, have chosen to pursue full silicon replacement
    - Partial replacement not viable: unacceptable level of technical risk, more down-time for removal/installation, limited SVX2 chip availability, etc.
- Trigger:
  - Increase in luminosity results in unacceptable increase in rates - occupancies, pileup, combinatorial effects
  - Move rejection upstream in readout stream (contain dead time), maintain both downstream rejection, event selectivity

Run 2b Philosophy

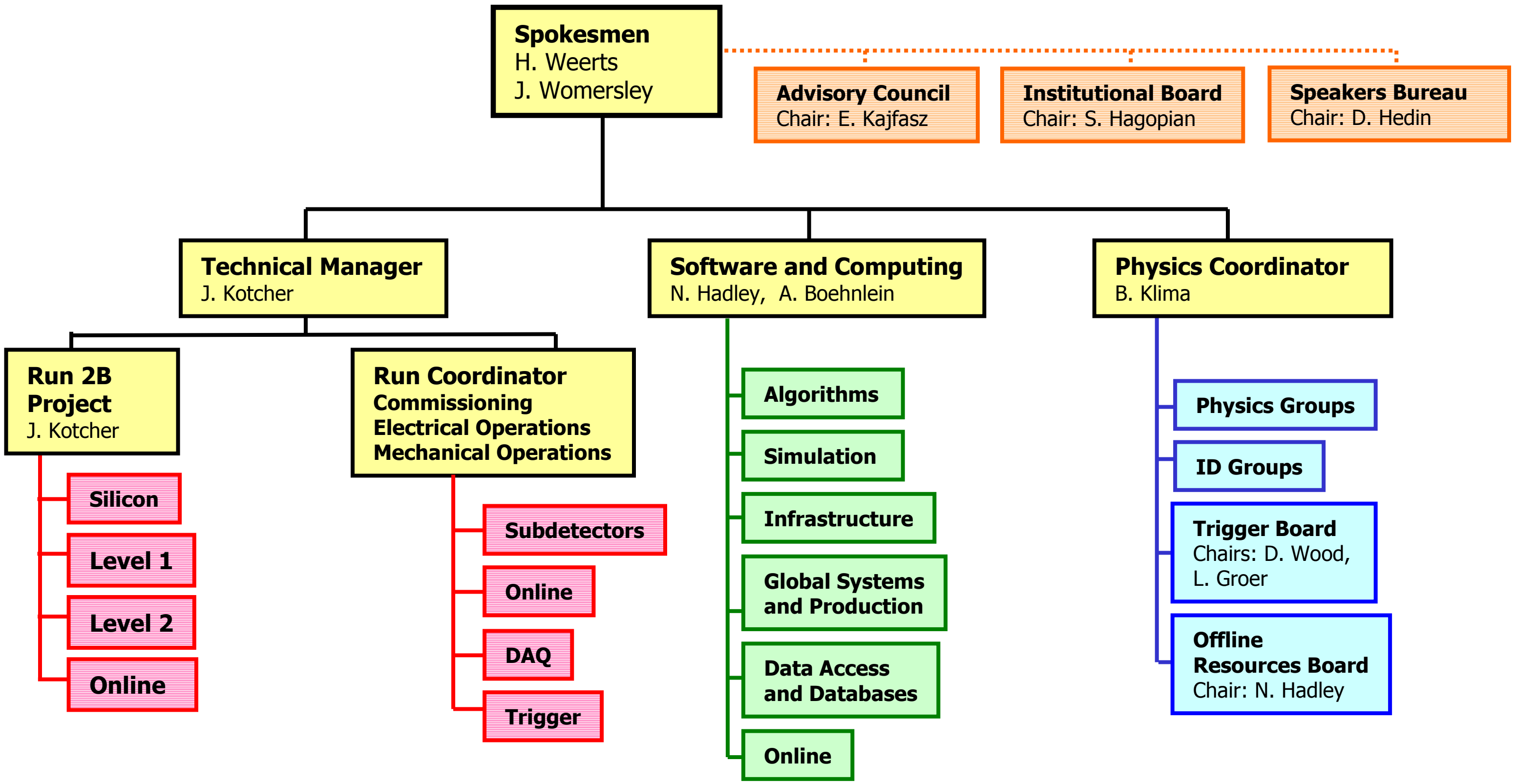
- Collaboration, Project Management has been designing Run 2b project with full awareness of tight constraints
  - Time scales abbreviated
  - Technical, financial resources not unlimited
  - Collaboration is, and will be, multi-tasking
    - Run 2b upgrade + commissioning, operations, data analysis, physics
- Have sought to limit scope, complexity wherever possible
  - Exploit existing designs, systems, experience
  - Effort to find alternatives to designs that require broad replacements of infrastructure
  - Carefully crafting sub-projects, assignments, & responsibilities
  - Modify course based on Run 2a results if necessary
  - Target high-p_T program exclusively

Aforementioned silicon detector and trigger upgrades are the two major ingredients deemed necessary in order to adequately pursue the Run 2b physics program

Sub-Project Overviews

- Silicon
  - Replace with more radiation-hard version
    - Improve impact-parameter resolution (b-tagging), maintain good pattern recognition, broad $|\eta|$ coverage
- Level 1 Trigger
  - Shift some trigger functionality upstream to hardware level trigger, increase overall Level 1 trigger capability – contain rates, dead time
    - Calorimeter clustering & digital filtering
    - Enhance track trigger to respond to increased occupancies
    - Calorimeter cluster matched with track
- Level 2 Trigger
  - Silicon Track Trigger (STT) upgrade to address increased occupancies, map to extended silicon detector
  - Incremental β-processor upgrade to maintain Level 2 rejection, event selectivity
- Online System
  - Address aging, obsolescence of computing hardware, need for higher bandwidth data logging, filtering capability

D0 Experiment Organization



Run 2b Project Organization

DØ Run 2b Project
(J. Kotcher), Project Manager
R. Partridge, Deputy
M. Johnson, Technical Coordinator

Project Office
W. Freeman
C. Yoshikawa

Silicon
M. Demarteau
A. Bean, Deputy

- Mechanical
  W. Cooper, (K. Krempetz)
- Sensor Accounting, Testing
  R. Demina, F. Lehner
- Electronics
  A. Nomerotski, N.W. Reay
- Production
  TBA
- QA, Testing, & Burn-in
  C. Gerber, TBA
- Simulation
  L. Chabalina, F. Rizatdinova
- Radiation Monitor
  S. de Jong

Level 1
H. Evans
D. Wood

- L1 Cal Upgrade
  M. Abolins, (H. Evans),
  P. LeDu
- L1 Track Trigger
  M. Narain
- L1 Cal/Track Match
  K. Johns
- Simulation
  M. Hildreth, E. Perez

Level 2
R. Hirosky
J. Linnemann

- L2β Upgrade
  (R. Hirosky)
- Silicon Track Trigger
  U. Heintz

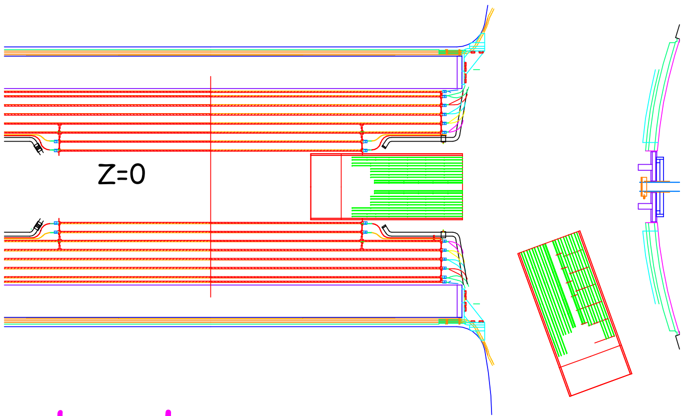
Online
S. Fuess
P. Slattery, Deputy

- Run 2b Upgrades
  (S. Fuess)

Level 1 trigger: most extensive non-silicon portion of Run 2b upgrade

Some Silicon Design Considerations, Boundary Conditions

- Installation within existing fiber tracker, with inner radius of 180 mm
- Full tracking coverage
  - Fiber tracker up to $|\eta| < 1.6$
  - Silicon stand-alone up to $|\eta| < 2.0$
- Installation in collision hall
  - Tracker will be built in two independent half-modules, split at z=0



- Simplicity, conservative approach:
  - Live within existing cable plant, reuse interface boards
  - Limit number of modules – 2 (axial+stereo) X 3 types (L2-5)
  - On-board electronics wherever possible (analog cables)
  - >15 fb^{-1} L0&1, >25 fb^{-1} outer layers
  - L0&1 mechanically distinct – staging if needed, future replacement?
  - Use established technologies, do not over-design (no 90-degree stereo)
- Luminous region: length of inner layer 96 cm, on plateau of luminosity acceptance
- Radiation damage requires silicon operating temperature of –10^{o}C, off-board electronics for innermost layer
- Respect 6-fold symmetry required by Silicon Track Trigger

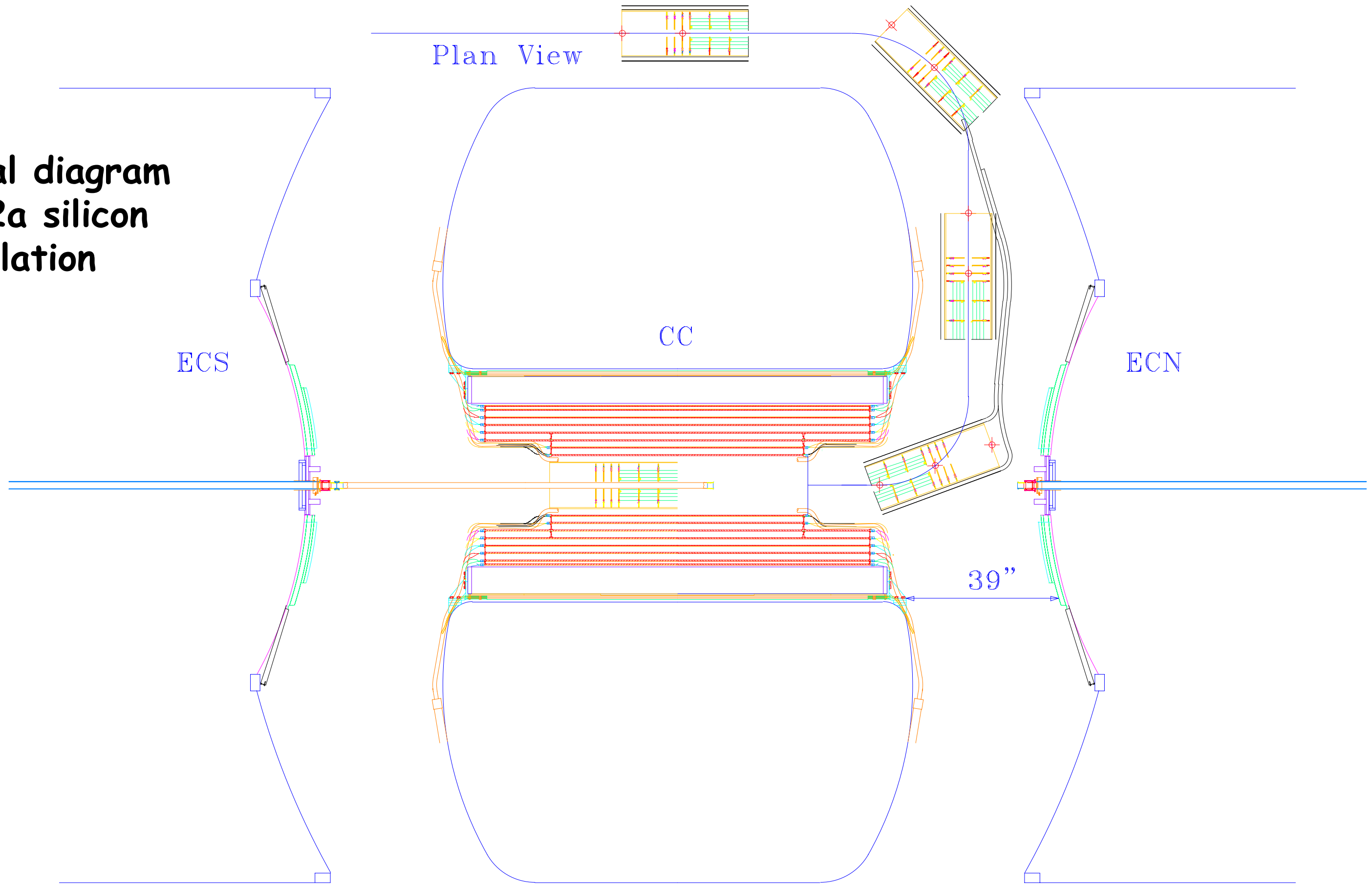
Run 2b Shutdown Constraints

Split-silicon design allows installation in Collision Hall

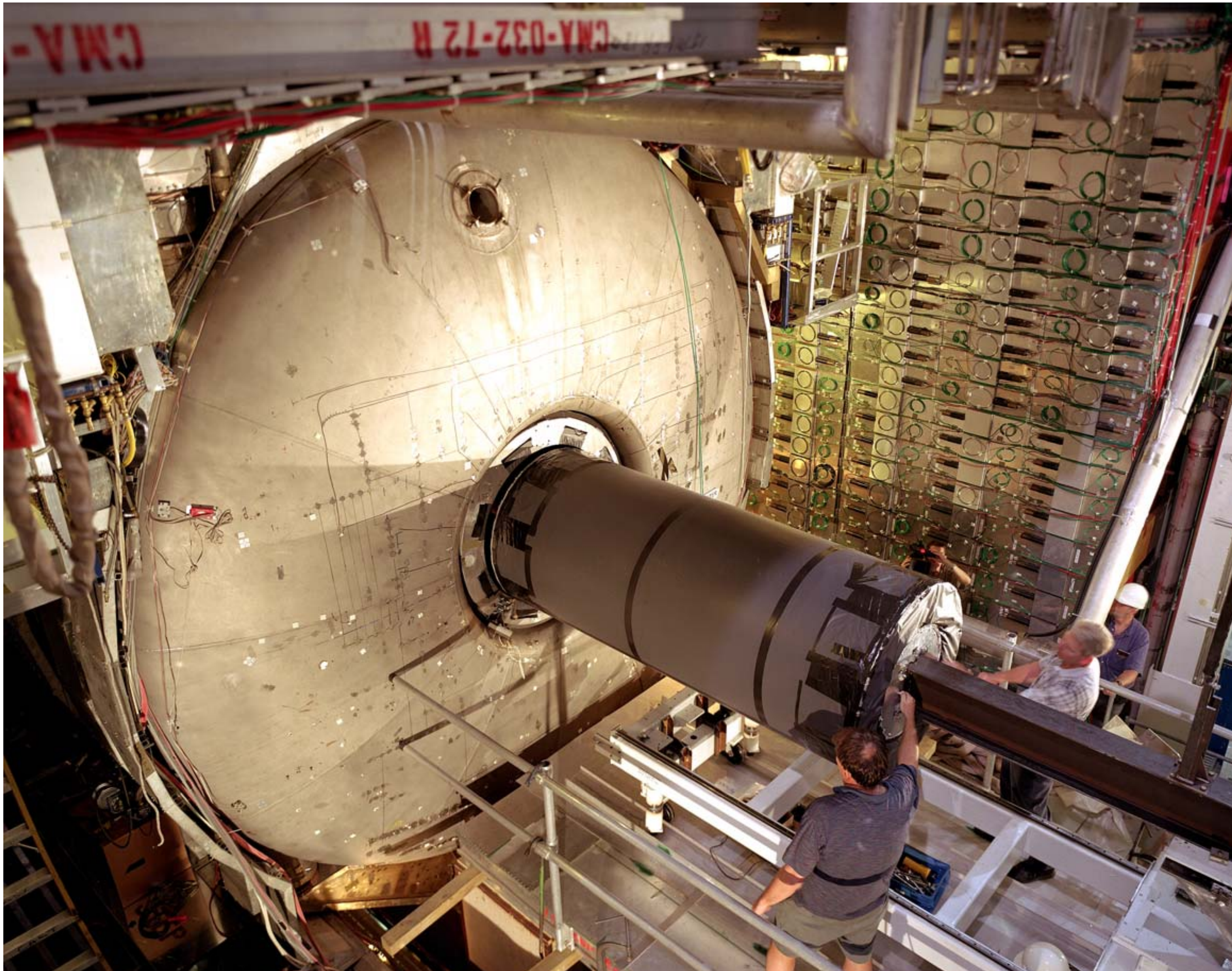
Platform not rolled out - much reduces time, effort, risk

Allows shutdown time to be dedicated to installation, hookup, commissioning

Conceptual diagram of Run 2a silicon installation



Fiber Tracker Insertion into Bore

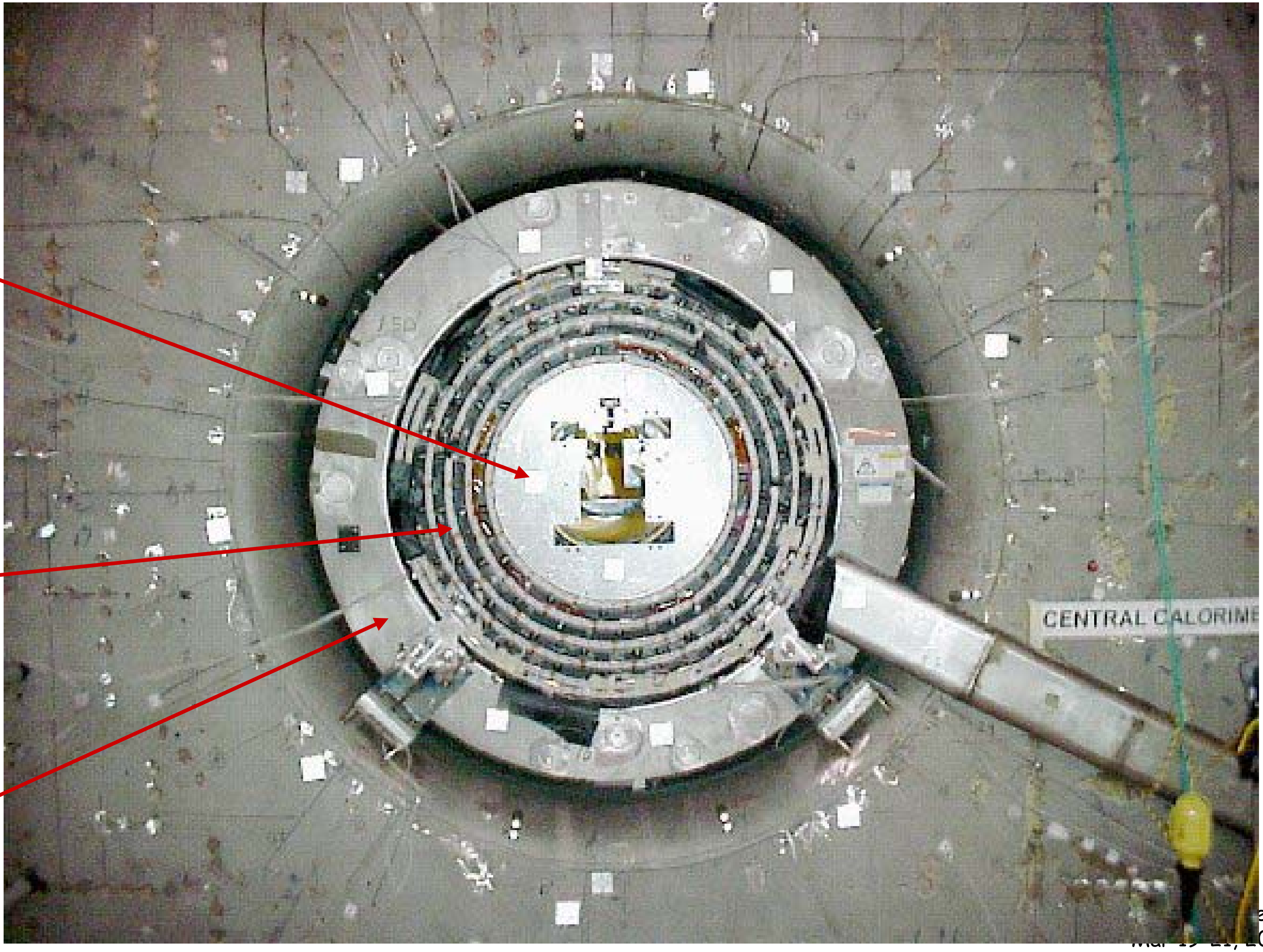


Fiber Tracker Installed in Bore

Inner bore for silicon

Fiber Tracker

Solenoid



Run 2a Silicon Installation
South Half-Barrel

SMT-S being transferred to transport truck

SMT-S inserted into CFT bore, between cryostats

Run 2b Shutdown

Silicon End Game

Activity	Duration wrt previous task
Shutdown begins	-
Silicon ready to move to DAB	12 weeks
Silicon installed in Fiber Tracker	3 weeks
Silicon cabling, commissioning begins	7 weeks
Commissioning complete, ready to close	10 weeks
TOTAL SHUTDOWN DURATION	~ 7 MONTHS

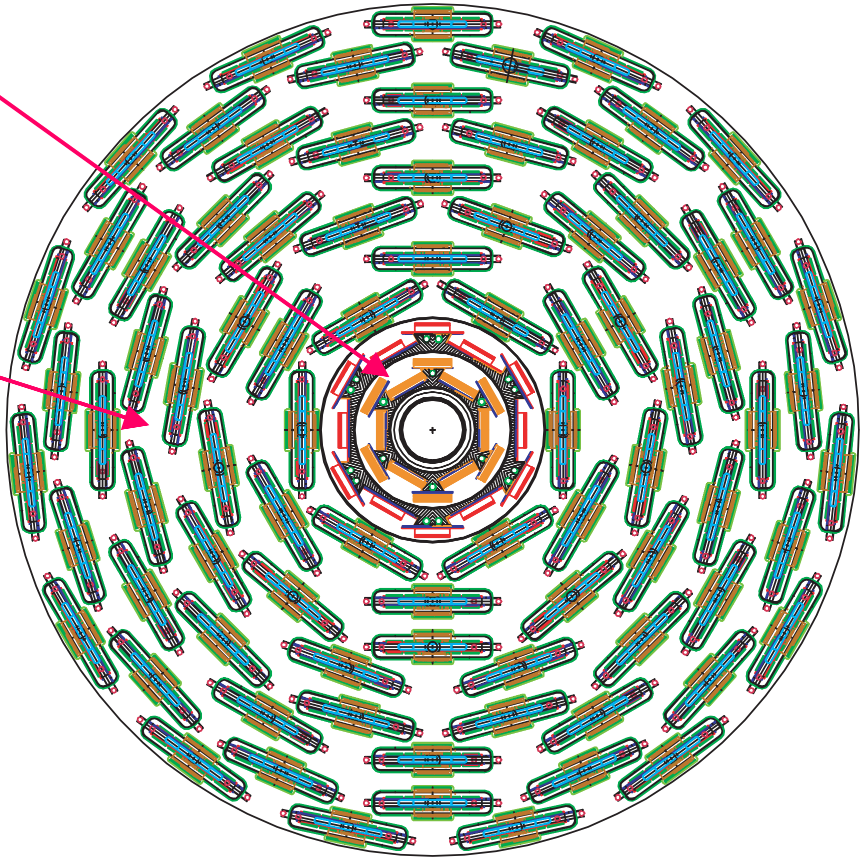
Durations obtained from resource-loaded silicon schedule, previous Run 2a experience

Schedule being fully reconsidered for upcoming series of reviews: consistent with 7 month shutdown beginning in CY05

- Timing, duration of shutdown driven by silicon
- Replacement of trigger elements require limited access to Collision Hall (Counting Rooms only)
- Ample time for installation of upgraded Level 1 trigger (2-3 months), but projects must be properly synched

Basic Design Choices

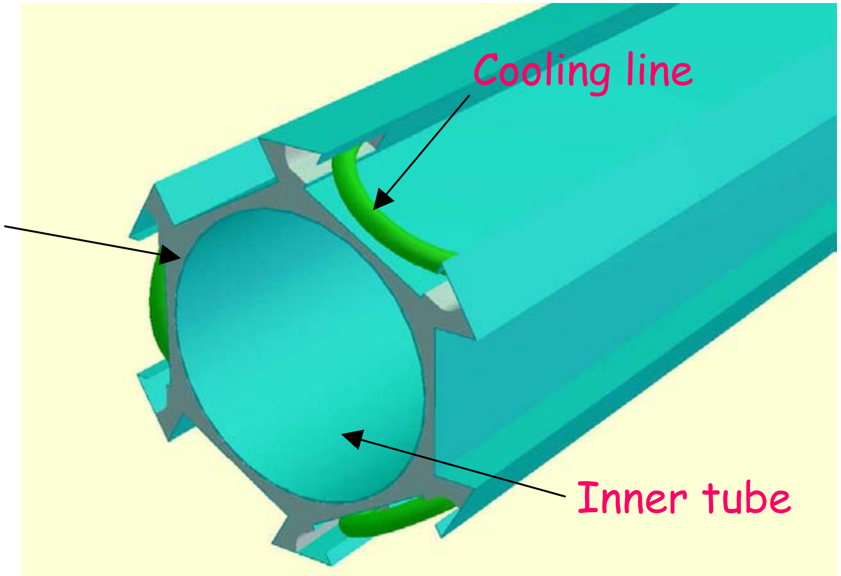
- Six layer silicon tracker, divided into two radial regions
  - Inner layers: Layers 0 and 1
    - Axial readout only
    - Mounted on integrated support
    - Assembled into one unit
    - Designed for V_{bias} up to 1000 V
  - Outer layers: Layers 2-5
    - Axial and stereo readout
    - Stave support structure
    - Designed for V_{bias} up to 300 V

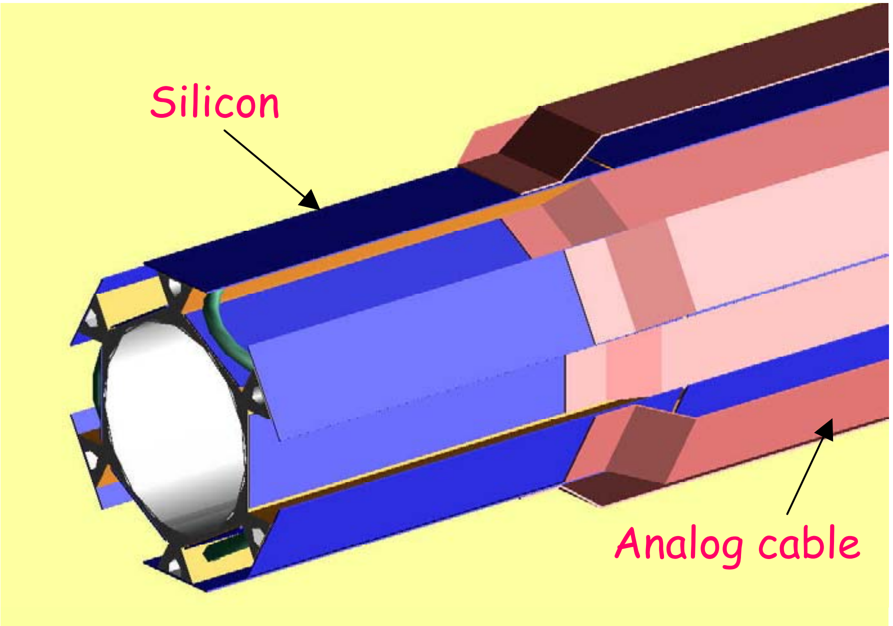


- Employ single sided silicon only, 3 sensor types
  - 2-chip wide for Layer 0
  - 3-chip wide for Layer 1
  - 5-chip wide for Layers 2-5
- No element supported from the beampipe
- Drilled Be beampipe with ID of 0.96", 500μm wall thickness

Silicon Layer 0

- **Support Structure**
  - 12-fold crenellated geometry
  - Carbon-fiber-lined carbon foam
  - Integrated cooling
  - R_{in} = 18.5 mm

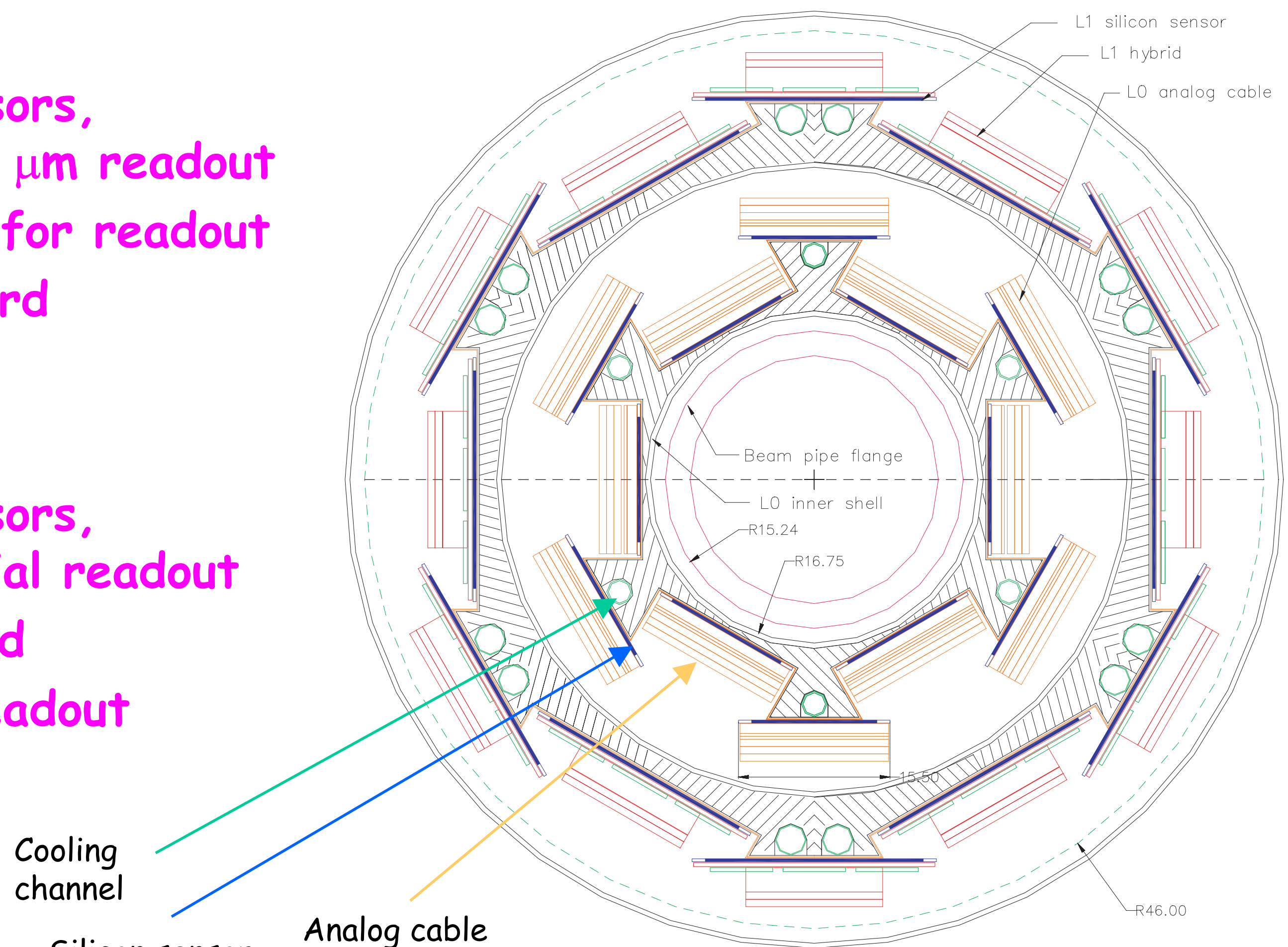




- **Assembly**
  - 2-chip wide sensors
  - 25 μm pitch, 50 μm readout
  - Analog cables for readout
  - Hybrids off-board

Silicon Inner Layers

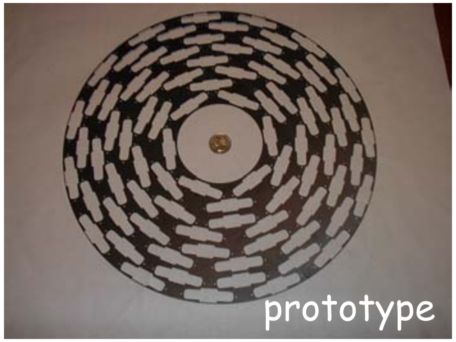
- Inner two layers have 12-fold crenellated geometry with carbon fiber lined, carbon foam support structure
- Layer 0
  - 2-chip wide sensors, 25 μm pitch, 50 μm readout
  - Analogue cables for readout
  - Hybrids off-board
  - R_{in} = 17.8 mm
- Layer 1
  - 3-chip wide sensors, 58 μm pitch, axial readout
  - Hybrids on-board
  - 6-chip hybrid readout
  - R_{in} = 34.8 mm

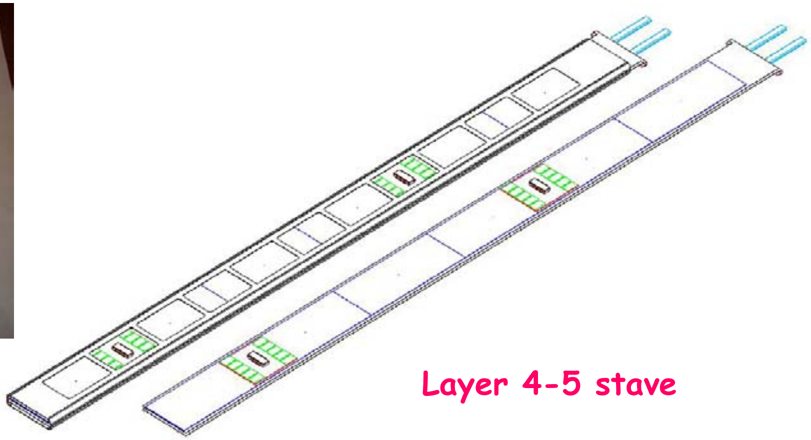


Cross-sectional view through silicon sensors

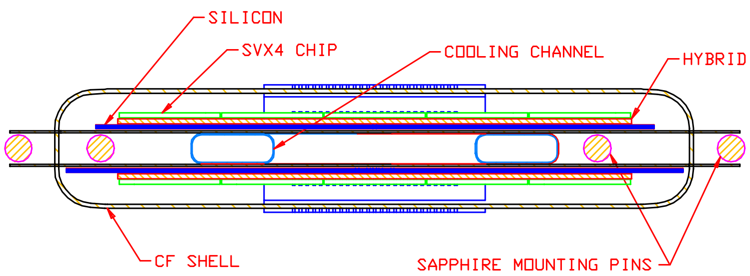
Silicon Stave Structure

- Stave is doublet structure of four readout modules
  - Two layers of silicon
    - Axial and stereo
    - Two readout modules each
  - separated by PEEK cooling lines
  - Total of 168 staves
- Staves are mounted in end carbon fiber bulkheads
- Stave has carbon fiber cover
  - Protect wirebonds
  - Provide path for digital cables
- Cooling manifold similar to bulkhead design

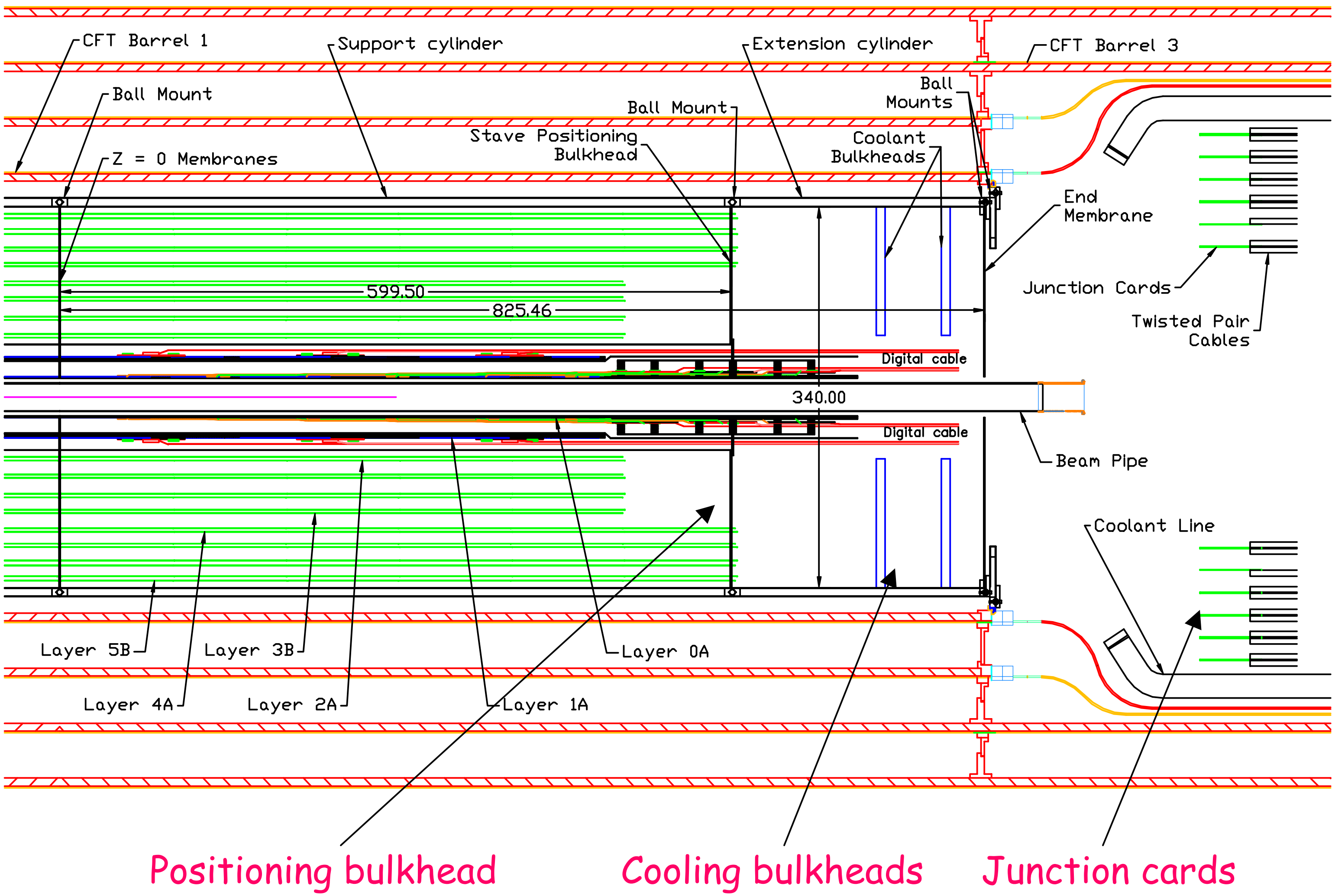




Layer 4-5 stave



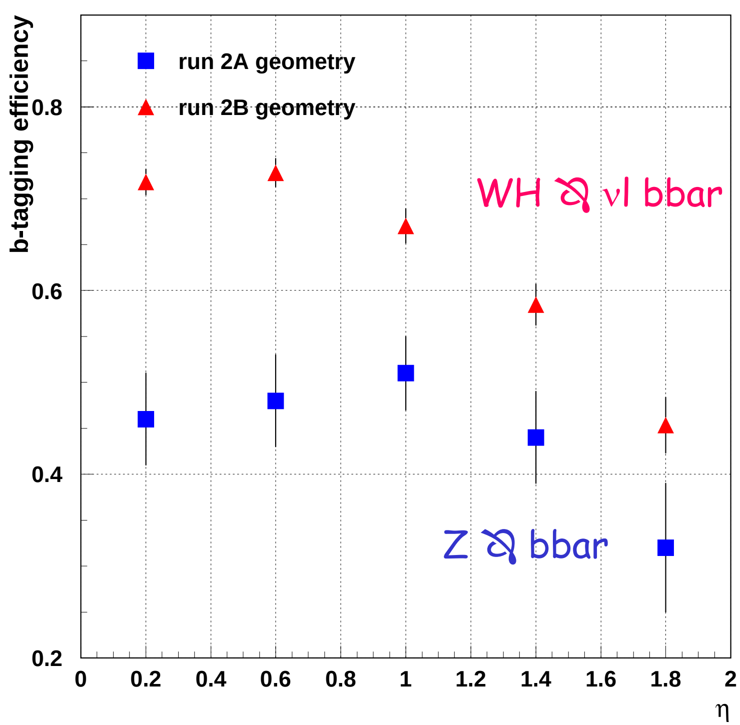
Run 2b Tracking System: Plan View

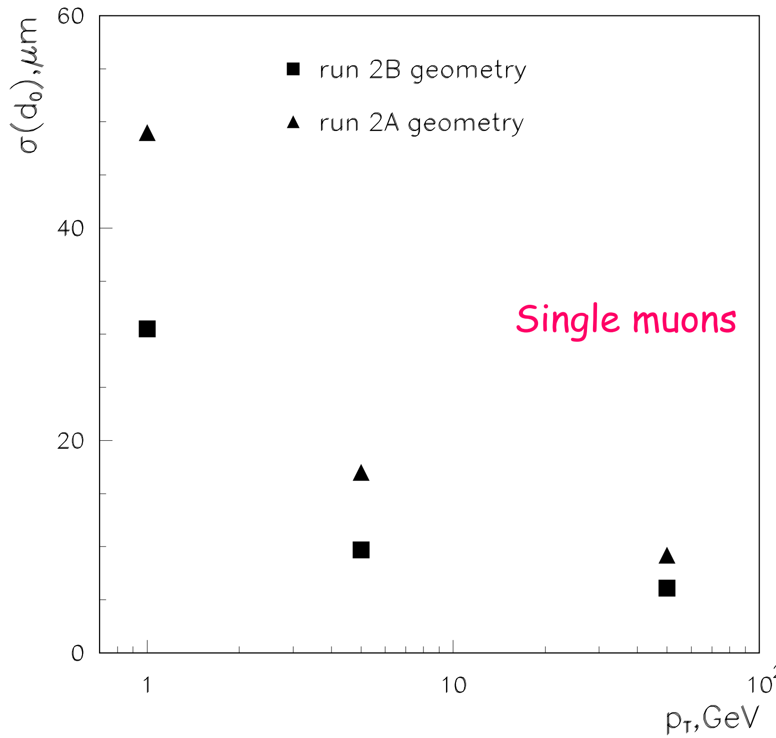


Silicon Tracker Performance

Expected performance of Run 2b vs. Run 2a silicon trackers, Full GEANT simulations

Mistag rate 1-2%



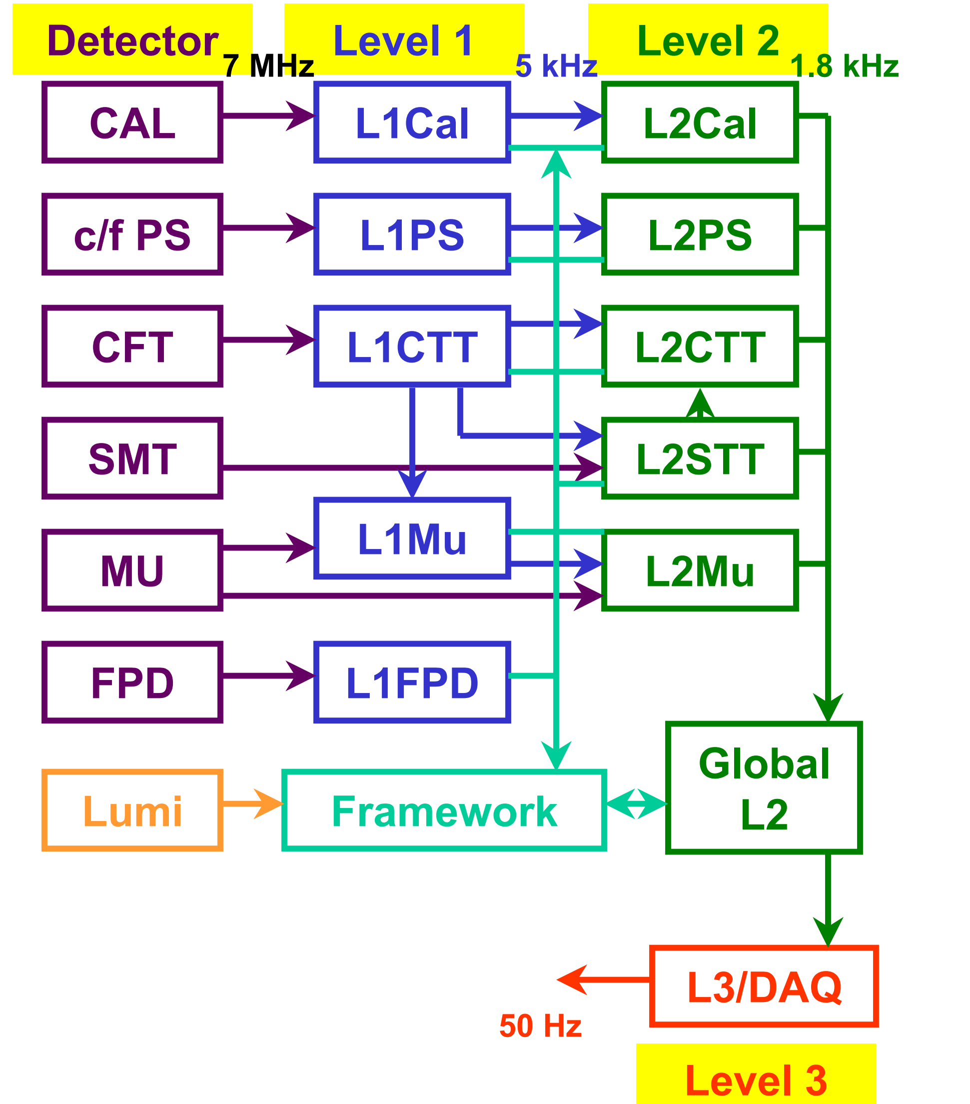


	Run2b	Run2a
$P(n_b >= 1)$	80%	68%
$P(n_b >= 2)$	35%	21%

Double b-tag efficiency improves X 1.6 compared with Run 2a detector

DØ Trigger Architecture

- Level 1
  - Calorimeter trigger
  - Fiber tracker trigger
  - Preshower (e/γ) trigger
  - Muon trigger
- Level 2
  - Silicon track trigger
  - Introduce correlations, refine Level 1 decision
- Level 3
  - Full event information available
  - Farm of high-performance computing nodes



Run 2b Trigger Task Force

- Run 2b Trigger Task Force in place Mon, 6/25/01:
  - Co-Chairs: M. Hildreth (Notre Dame), R. Partridge (Brown U)
- Calorimeter
  - M. Abolins (MSU)
  - D. Baden (UMaryland)
  - B. Kehoe (MSU)
  - P. Le Du (Saclay)
  - E. Perez (Saclay)
  - M. Tuts* (Columbia)
  - V. Zutshi (BNL)
- Technical/Hardware
  - D. Edmunds (MSU)
  - M. Johnson* (Fermilab)
  - J. Linnemann (MSU)
  - D. Schamberger (Stony Brook)
- Tracking
  - B. Abbott (UOklahoma)
  - D. Alton (UMichigan)
  - V. Bhatnagar (Orsay)
  - F. Borcherding (Fermilab)
  - S. Chopra (BNL)
  - F. Filthaut (UNijmegen)
  - Y. Gerstein (Brown U)
  - G. Ginther* (URochester)
  - P. Petroff (Orsay)
- Muon
  - J. Butler (Boston U)
  - K. Johns* (UArizona)

* = Sub-Group Chair

The Run 2b Level 1 Trigger Challenge

Run 2 Working Group results assume:

- ~100% Leptonic Trig. eff.
- ~100% L1 eff. for $ZH \rightarrow \nu\nu bb$
  - ME_T>35 GeV + topo jet cuts

The triggering challenge for Run 2b:

- High P_T Trig's > Bandwidth at $\mathcal{L} = 5\times10^{32}$ cm^{-2}s^{-1}

Trigger	Physics	L1 rate (kHz)
EM Trigger Tower > 10 GeV	$W \rightarrow e\nu$	5
Track Trigger 2Trks (5,10GeV) + Iso + EM>2GeV	$H \rightarrow \tau\tau$	10
Jet Trigger 2 H+EM towers Σ > 4GeV	$ZH \rightarrow \nu\nu bb$	2

5 kHz total bandwidth budget

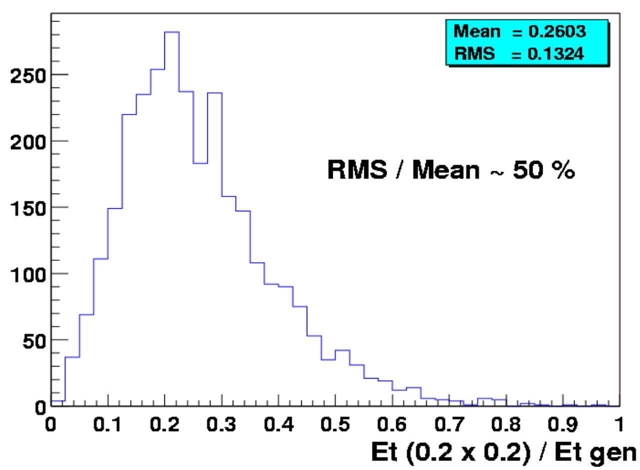
DØ Studies:

- Trigger Task Force
  - Develop plan for Run 2b Trigger System
  - Tracking, Calorimeter, Muon, Tech/H'ware
  - Produced report Sep '01
- Conceptual Design Report
  - Refine TTF report
  - Focus on Level 1
  - Feasibility arguments for Level-2,3
  - Report: Oct. 14 '01
- Currently preparing detailed Technical Designs
  - April '02 Reviews

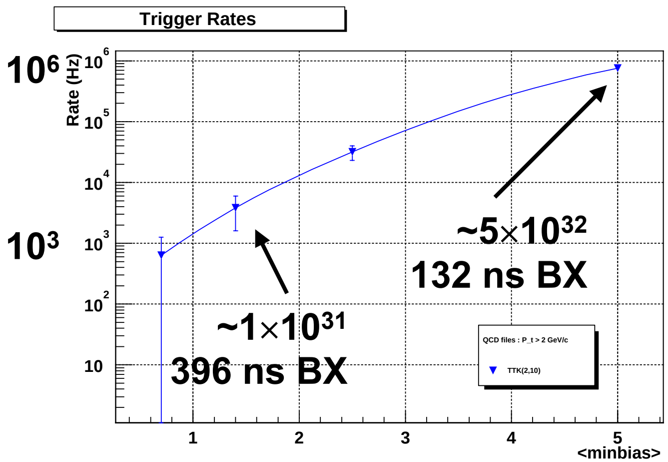
Run 2b Level 1 Trigger Upgrade

System	Problems	Solutions
Cal	1) Slow signal rise $\Rightarrow$ trig on wrong X'ing 2) Trig on $\Delta\eta\times\Delta\phi$=0.2×0.2 TTs $\Rightarrow$ slow turn-on curve	• Digital Filter • Clustering
Track	1) Rates sensitive to occupancy $\Rightarrow$ ×1000 increase 2a→2b	• Narrower Track Roads • Improve Cal-Track Match
Muon	No Additional Changes Needed!	• Requires Track Trig

Cal Jet Resolution



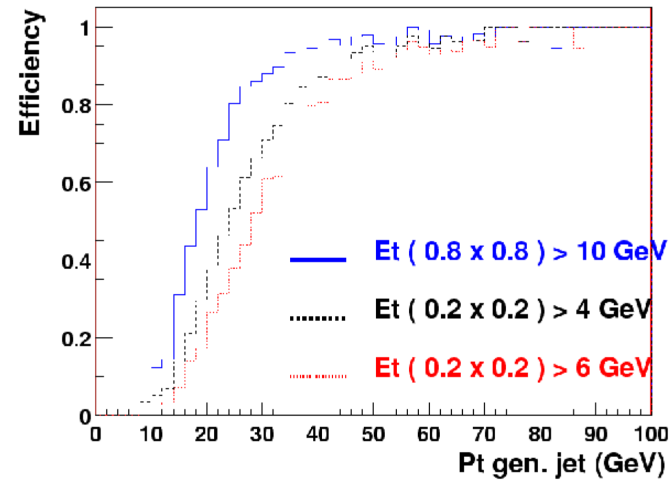
2 Track Trigger Rate (Hz)



Calorimeter Trigger Tower Clustering

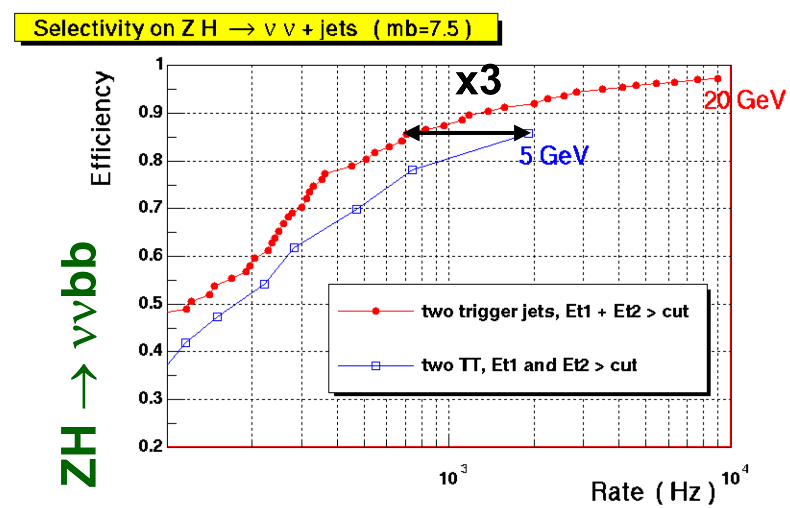
Problem

- Jets clusters > TT size
- EM clusters fall on boundary
- Poor E-res → Shallow turn-on curves



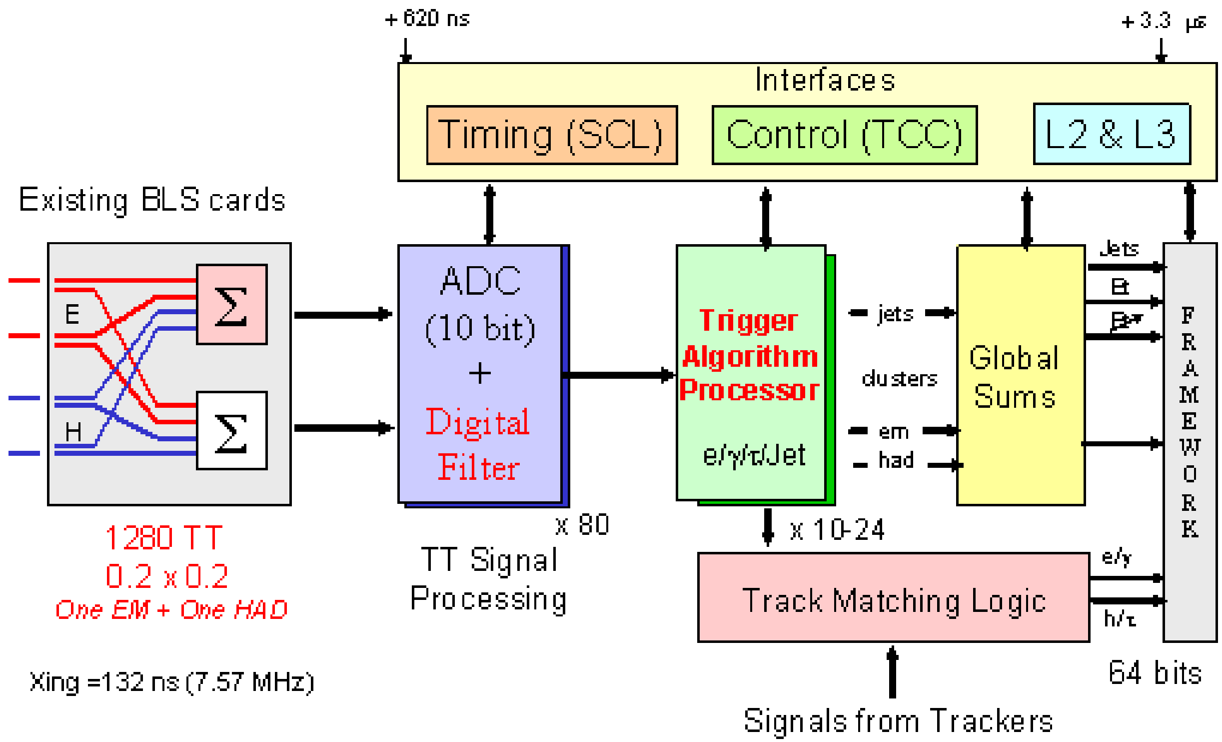
Possible Solution

- TT Clustering:
  Atlas sliding windows
- Additional Benefits
  - EM shape & Isolation cuts
  - Topological Triggers
  - Include inter-cryo region in Global Sums
- Include output for Track Matching



Level 1 Calorimeter Trigger Upgrade

- Clustering algorithm is implemented in FPGA's
- Similar to ATLAS sliding-window algorithm



Calorimeter Trigger: Columbia University, Michigan State University, Saclay

Track Trigger Upgrade

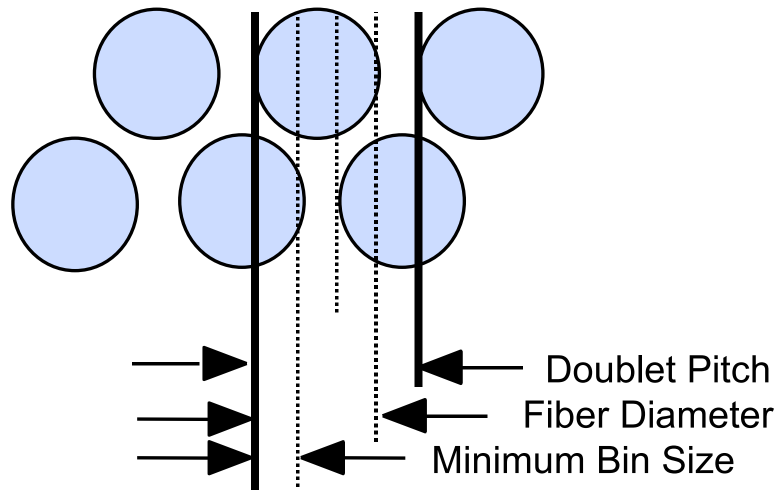
Problem

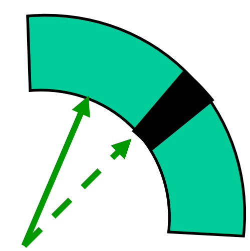
- Rate soars w/ Occupancy
  - 10^6 Hz at 5×10^{32} (5 min-bias)

Solutions

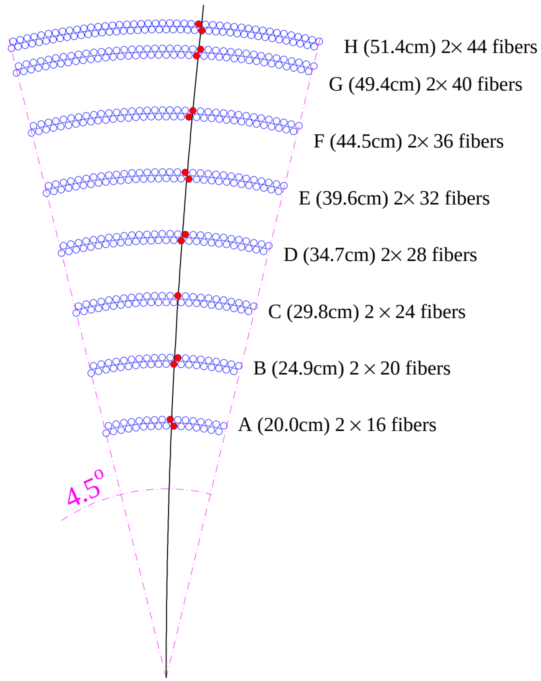
1. Reduce size of track finding road: use single fiber instead of doublets
   - No. eqn's increases
   - Tune no. of layers using singlets
   - Use same system with new FPGAs in DFE's
2. Cal-Track Matching
   - New Cal Trig could provide $\times 8$ finer granularity for matching
   - Modest extension of Cal upgrade

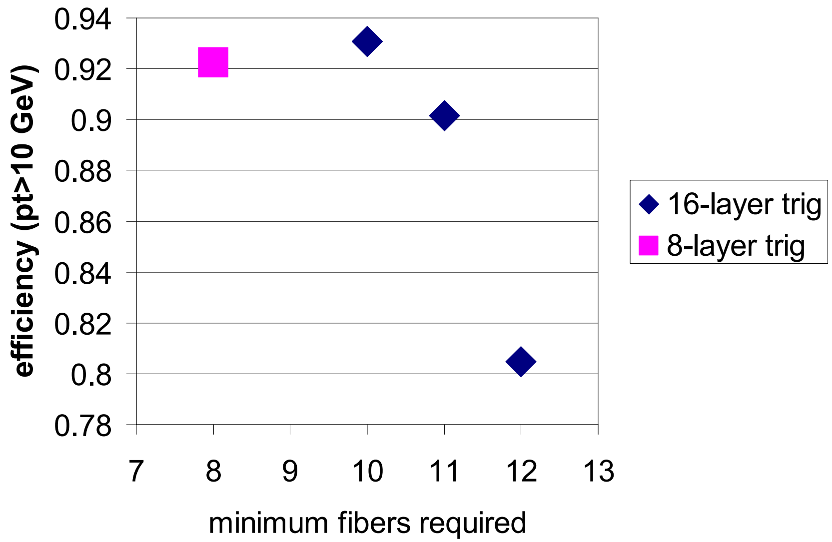
Doublet Layer





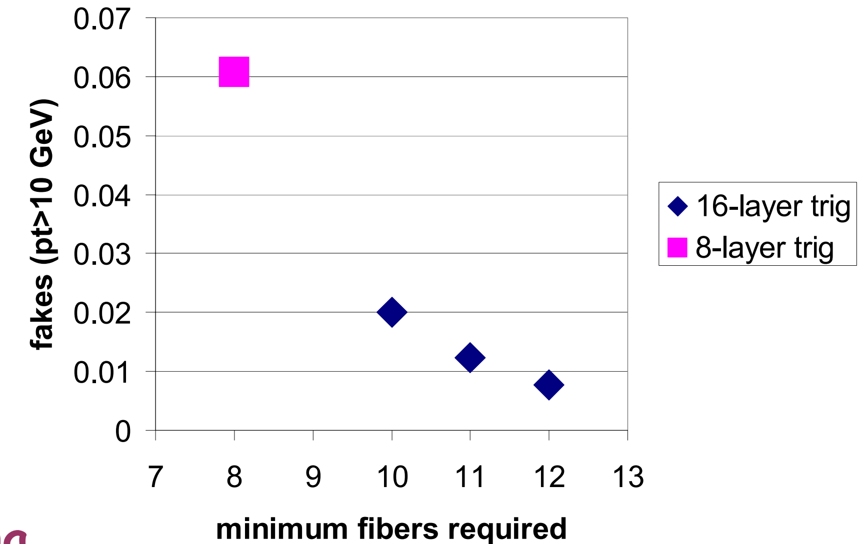
Track Trigger Upgrade





Cal-Track Match Bkgrd Rej Gains:

- EM Triggers: ×2
- High P_T Tracks: ×10



Track Trigger: Boston University
Cal/Track Matching: University of Arizona

Run 2b Level 1 Trigger Upgrade: Expected Rates for Key Processes

- $L = 5\times10^{32}\ cm^{-2}s^{-1}$

Trigger	Physics	Level 1 rate, no upgrades (kHz)	Level 1 rate, with upgrades (kHz)
EM tower>10 GeV	$W \rightarrow e\ \nu$	5	0.3 (cal/track matching, 16-layer CTT, EM fraction)
2 Tracks (>10 & 5 GeV) + isolation + EM>2 GeV	$H \rightarrow \tau^+\tau^-$	10	1 (cal/track matching)
2 Had+EM towers, sum>4 GeV	$ZH \rightarrow \nu\nu bb$	2	0.6 (calorimeter clustering)

Upgraded trigger within 5 kHz Level 1 bandwidth budget

Run 2b Project Status

- Upper tier of project management in place Jun '01
- All WBS Level 2 sub-project managers chosen Sep '01
  - Mix of past D0 project experience, fresh blood
  - Most silicon sub-task managers identified
    - Strong, experienced group, actively collaborating on new design, R&D
  - Most trigger sub-task managers chosen, institutional assignments made
  - Strong university participation at all levels
    - NSF MRIs: approved (silicon), submitted (Level 1 trigger)
- Silicon project very mature, design complete, Technical Design Report in hand
- Trigger Conceptual Design Report submitted, converging on final technical designs
- Schedule, cost estimate very detailed, being fleshed out & reconsidered for upcoming Director's (April 16-18), Lehman Reviews
  - Silicon schedule 860 lines, fully resource loaded
  - Cost estimate sharpening, more quotes in hand
  - All other necessary ingredients being prepared:
    - Basis for estimate, risk analyses, earned-value reporting, etc.

US National Science Foundation MRIs for Run 2b

- Silicon MRI submitted Feb '01, approved July '01
  - Brown, California State (Fresno), U Illinois (Chicago), Kansas, Kansas State, Michigan State, Northwestern, Stony Brook, Washington, (Moscow State, CINVESTAV)
    - Principal Investigator: A. Bean
    - Co-PIs: R. Demina, C. Gerber, R. Partridge, G. Watts
  - \$1.7M + \$0.7M matching = \$2.4M total
- Level 1 trigger MRI submitted January '02
  - Level 1 calorimeter, track trigger, cal/track match
  - Arizona, Boston, Columbia, Florida State, Langston, Michigan State, Northeastern, Notre Dame, (Saclay)
    - Principal Investigator: M. Narain
    - Co-PIs: H. Evans, U. Heintz, M. Hildreth, D. Wood
  - Request \$2.6M total
    - \$1.3M equipment (includes \$0.2M matching)
      - Approximately covers cost of sub-projects, but without contingency (50%)
    - \$1.3M labor (includes \$0.4M matching)
- Underscores major role universities continue to play in mounting DO projects, realizing our physics program

Run 2b M&S Cost Estimate

As presented at Director's Technical Review, Dec '01

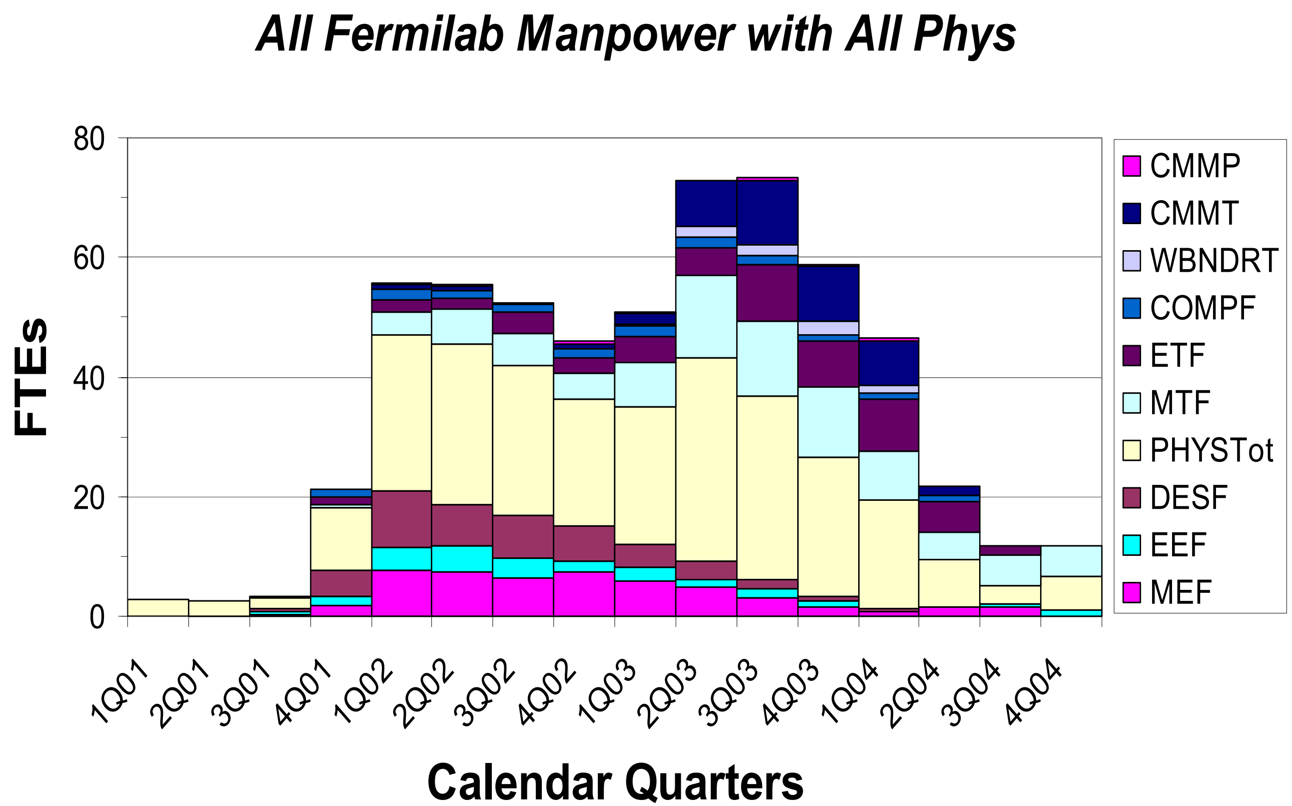
Sub-Project	M&S ($k)	Contingency (%)	Total ($k)	Approx. Fiscal Year Needed	Comments
Silicon	8,101	42	11,499	FY02-04	FY02: sensors, electronics, mechanical D0 NSF MRI: $(1.7+0.7)M
Level 1 Calorimeter Trigger	726	50	1,089	FY03-04	Most extensive portion of Level 1 trigger upgrade
Level 1 Cal/Track Matching	97	50	146	FY02-03	Utilize existing Run 2a Muon Trigger Cards
Level 1 Track Trigger	359	50	539	FY03-04	Fiber singlets; use DFE layout
Level 2 Silicon Track Trigger	402	48	593	FY02-04	Full 6-layer STT upgrade
Level 2β Upgrade	72	37	98	FY03-04	New processors
Online	950	17	1,116	FY02-06	Assumed from operating, not included in TOTALS below
TOTAL M&S	$9,757k	43	$13,964k		

Total FNAL Technical Manpower for Silicon Project

As presented at Director's Technical Review, Dec '01

All Fermilab technical manpower, plus all physicists (FNAL + Universities)

FNAL Resources	Person-yrs
CMM Prog	0.6
CMM Tech	10.2
Computing Prof.	3.9
Designer/Drafter	11.0
Electrical Engineer	5.7
Electrical Tech	13.1
Mechanical Engineer	12.6
Mechanical Tech	22.0
Wire Bonder	1.8
Total	80.9
Physicist (FNAL)	28.2
Physicist (Other)	37.6



Total Project Cost

As presented at Director's Technical Review, Dec '01

					0.10								0.31			
Sub-Project	M&S					Total	Labor							Total	TOTAL	TOTAL
	Cost(k$)	Cont(%)	Cont(k$)	Total(k$)	Ind	M&S	F	U	Cost(k$)	Cont(%)	Cont(k$)	Total(k$)	Ind	Labor	(FY02k$)	(ThenYk$)
Silicon	8,102	42	3,403	11,504	1,150	12,655	4,818	1,201	6,019	50	3,009	9,028	2,775	11,804	24,459	25,218
Level 1 Cal Trigger	726	50	363	1,089	109	1,198	56	621	676	50	338	1,014	312	1,326	2,523	2,603
Level 1 Cal Track Matching	97	50	49	146	15	160	30	62	92	50	46	139	43	181	341	352
Level 1 Track Trigger	359	50	180	539	54	592	5	125	130	50	65	195	60	255	847	871
Level 2 Silicon Track Trigger	402	48	193	595	59	654	13	129	141	50	71	212	65	277	931	958
Level 2 β Upgrade	72	37	27	99	10	109	0	19	19	50	10	29	9	37	146	150
TOTAL PROJECT COST	9,757	43	4,213	13,970	1,397	15,367	4,921	2,157	7,078	50	3,539	10,616	3,263	13,880	29,247	30,153

- Includes all ingredients: contingency estimates on both M&S & labor, indirect costs, escalation
- Updated TPC being prepared for upcoming April reviews

Conclusions

- Run 2b has matured into a solid, well-defined project
  - Scope carefully crafted to Run 2b physics goals
  - Silicon design very advanced, R&D underway
  - Trigger needs well established, final technical designs being aggressively pursued
  - Project management in place, most lead individuals identified, major institutional assignments made
  - Strong personnel/groups in place at all levels
- Fully resource-loaded schedule, cost estimate in place
  - Being refined for upcoming series of reviews
  - Very detailed, conservative approaches taken throughout
  - Time, other contingencies undergoing special scrutiny
  - Lab guidance being integrated as project develops
- Look forward to obtaining necessary approval for construction $ at June Baselining Review